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ARE CORAL CLAISTS FROM A TURBID NEAR-SHORE REEF ENVIRONMENT A SUITABLE MATERIAL FOR RADIOCARBON ANALYSIS?

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ABSTRACT. Use of coral skeletons to determine growth histories of reefs situated in warm, clear tropical waters is well established. Recently, however, there has been increasing awareness of the significance of reefs occurring in environments that are considered as marginal for coral growth, such as turbid inshore settings characterized by episodes of elevated turbidity, low light penetration, and periodic sediment burial. While these conditions are generally considered as limiting for coral growth, coral reefs in these settings can exhibit high live coral cover and species diversity, and thus can be both ecologically and geologically significant. Turbid-zone reefs are also commonly concentrated along eroding shorelines with many analogues to erosional shorelines developed during the Holocene transgression. A growing number of studies of these previously undocumented reefs reveal that the reef deposits are detrital in nature, comprising a framework dominated by reef rubble and coral clasts and set within a fine-grained terrigenous sediment matrix. In addition to the recognized effects of diagenesis or algal encrustations on the radiocarbon signature of coral samples, episodic high-energy events may rework sediments and can result in age reversals in the same stratigraphic unit. As in other reef settings, the possibility of such reworking can complicate the reconstruction of turbid-zone reef growth chronologies. In order to test the accuracy of dating coral clasts for developing growth histories of these reef deposits, 5 replicate samples from 5 separate coral clasts were taken from 2 sedimentary units in a core collected from Paluma Shoals, an inshore turbid-zone reef located in Halifax Bay, central Great Barrier Reef, Australia. Results show that where care is taken to screen the clasts for skeletal preservation, primary mineralogical structures, and $\delta^{13}\text{C}$ values indicative of marine carbonate, then reliable ^{14}C dates can be recovered from individual turbid reef coral samples. In addition, the results show that these individual clasts were deposited coevally.

INTRODUCTION

While it is documented that corals can grow and form reef structures in turbid environments (see Sanders and Baron-Szabo 2005; Browne et al. 2012 for reviews), coral reefs are typically associated with warm, clear tropical waters. Within these environments the processes that influence reef growth have been widely described and have come to represent the norm against which coral reefs are defined. Rapid coral growth and reef sediment production typically result in the accumulation of extensive carbonate-dominated reef structures. Growth histories from many such reef settings have been interpreted via detailed radiocarbon dating and thus there exist well-constrained Holocene growth models for many island fringing, mid- and outer-shelf, and oceanic atoll reef systems (Kennedy and Woodroffe 2002; Gray and Hein 2005; Shaked et al. 2005; Rees et al. 2006).

In the past decade or so, there has been increasing awareness and understanding of the spatial significance of reefs that occur in a range of settings considered more marginal for coral growth such as those developed along the inner Great Barrier Reef (GBR), Australia (Larcombe et al. 2001; Smithers et al. 2006). These include nearshore areas influenced by elevated turbidity and high sedimentation regimes and which are of particular interest because they are not only abundant in modern locations but also have numerous analogues in the geological record (Kleypas et al. 1999; Perry and Larcombe 2003; Sanders and Baron-Szabo 2005). Despite the limiting effects of reduced light penetration and episodic sediment burial (Rodgers 1990), these reefs often exhibit high live coral cover and high coral species diversity and stability (Fabricius et al. 2005; De Vantier et al. 2006;

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Sweatman et al. 2007; Perry et al. 2008, 2009; Browne et al. 2010). They are thus highly significant from an ecological perspective as sites of nearshore reef biodiversity. From a geological perspective, these reefs develop in positions along terrigenous sediment-dominated shorelines and form important localized sites of carbonate production and accumulation (Perry 2003; Mallela and Perry 2007; Browne et al. 2012, 2013). In this context, they are important to our understanding of temporal and spatial variations in the timing and nature of cross-shelf coral reef development. The location of some of these turbid-zone reefs along actively eroding sedimentary shorelines not only represents a distinctive type of reef setting (and one not traditionally associated with reef development), but also represents a potentially important analogue for past phases of reef initiation since similar erosional shorelines will have developed and migrated landward across many shelf systems during the Holocene transgression (Larcombe and Woolfe 1999). Finally, the long-term influence exerted on these reefs by terrigenous-clastic sediments also means that they represent useful analogues for those reefs systems that are subject to the effects of increasing terrigenous sediment influence (widely cited as a major threat to reef ecosystems globally, McLaughlin et al. 2003).

By definition, these reefs are located in areas of shallow water depth and as such are susceptible to wind-driven wave resuspension of sediment, especially during storm events. The sedimentary structure of this reef type can be volumetrically dominated by silts and muds that support primarily detrital coral clast-dominated facies (Smithers and Larcombe 2003). In cores recovered from these reefs, some coral material, notably massive species such as *Porites* sp. and various *Favids*, can often reliably be inferred to be in the original growth position (*in situ*) using growth structures and other features, but detrital coral fragments, or clasts, often have been detached from the parent coral (e.g. fragments of branching corals such as *Montipora digitalis* and *Acropora* sp. or foliaceous corals such as *Turbinaria* sp. comprise a large proportion of the recovered coral material).

Given the potential vulnerability of these locations to reworking during storm events, it is not unreasonable to question whether these detrital coral facies are composed of coral clasts of equivalent age or whether they contain reworked clasts with a wide range of ages. This question was investigated using replicate coral clasts recovered from 2 discrete depth intervals of a core collected in 2005 from Paluma Shoals, Great Barrier Reef, Australia.

SAMPLE SITE

Paluma Shoals consists of a series of nearshore, turbid-zone reefs located in shallow water in Halifax Bay, central Great Barrier Reef (GBR), Australia (Figure 1A–D). They occur between the landward edge of the “inshore sediment prism” and the mainland coast, where wind- and wave-driven sediment resuspension produces episodes of high turbidity throughout the year (Larcombe and Woolfe 1999; Larcombe et al. 2001; Browne et al. 2012, 2013). These high turbidity conditions have persisted at Paluma Shoals since sea level stabilized in the mid-Holocene, with the internal structure of these reefs dominated by unconsolidated coral rubble with a clastic-carbonate sediment matrix (Smithers and Larcombe 2003; Palmer et al. 2010). The detrital nature of the deposits is largely due to periodic storms that generate storm rubble, although taphonomic evidence suggests that many colonies have to a degree collapsed in on themselves and were rapidly buried. The shoals are presently a site of active coral growth, with live coral cover varying across the North and South Shoal (reaching up to ~80% across the reef flat on the South Shoal) comprising numerous large *Goniastrea* microatolls as well as extensive colonies of *Galaxea* and *Porites*.

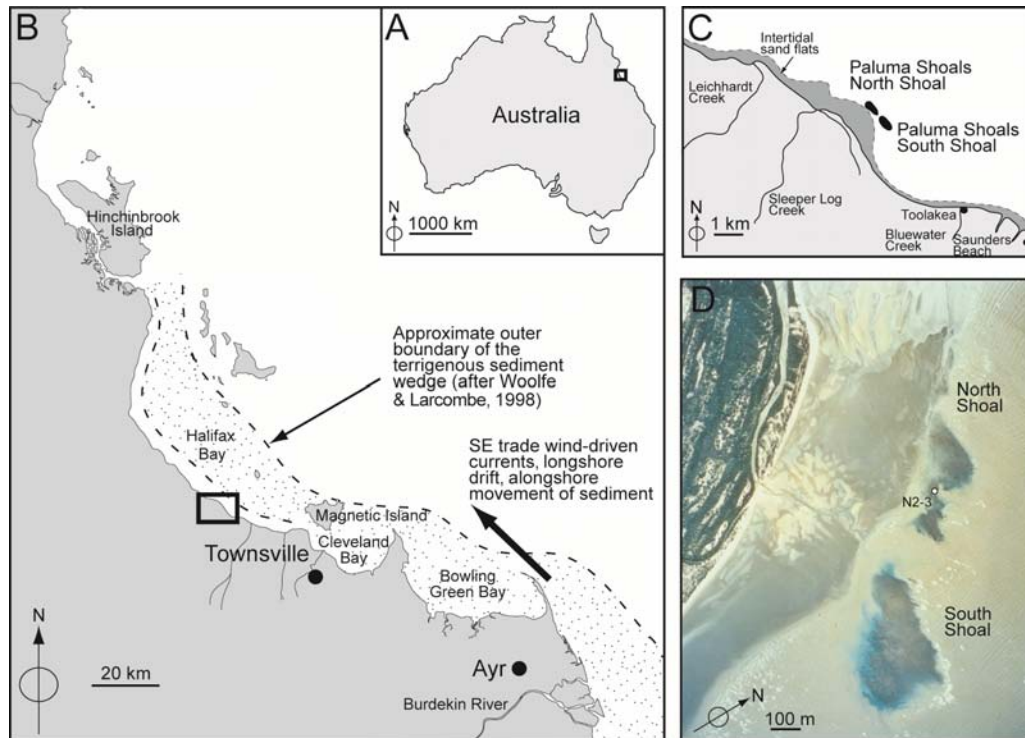


Figure 1 Location of Paluma Shoals (A–C), Halifax Bay, central Great Barrier Reef, Australia, and location of the core (D) recovered for this study from the North Shoal (after Palmer et al. 2010).

METHODS

Core N2-3 (Figures 1 and 2) was collected in 2005 from the North Shoal using manual percussion coring techniques. Through trial and error, we have established that this is the most effective method for recovering intact and relatively undisturbed cores from inshore turbid zone reefs. The core had 100% recovery and terminated in Pleistocene clay, confirming that the entire sequence of Holocene reef growth had been recovered. Rates and depths of core penetration were recorded to ensure a reliable depth chronology was established and to constrain sediment compaction.

The core was logged and coral samples selected for the purposes of biosedimentary facies analysis and ^{14}C dating (Perry et al. 2009; Palmer et al. 2010; Figure 3). Coral clasts of sufficient size were first selected and identified to species level before surficial encrustations were trimmed and then closely examined so that samples with high levels of internal bioerosion, intraskeletal cementation, and/or sediment infilling were rejected (Perry and Smithers 2006 and references therein). The chosen clasts were then washed in distilled water, ultrasonically cleaned to ensure removal of fine particles, and then oven-dried at 40 °C. Samples were then sent to the NERC Radiocarbon Facility-East Kilbride for ^{14}C analysis where the outer 20% by weight of sample was removed by controlled hydrolysis with dilute HCl. The samples were then rinsed in deionized water, dried, and homogenized. A known weight of the pretreated sample was hydrolyzed to CO_2 using 85% orthophosphoric acid at 25 °C. Sample CO_2 was cryogenically purified and collected prior to conversion to graphite by Fe/Zn reduction. Graphite targets were analyzed at the SUERC AMS facility using a 5 MeV tandem AMS (Freeman et al. 2007). A separate aliquot of sample CO_2 was analyzed for its $\delta^{13}\text{C}_{\text{VPDB}}$.

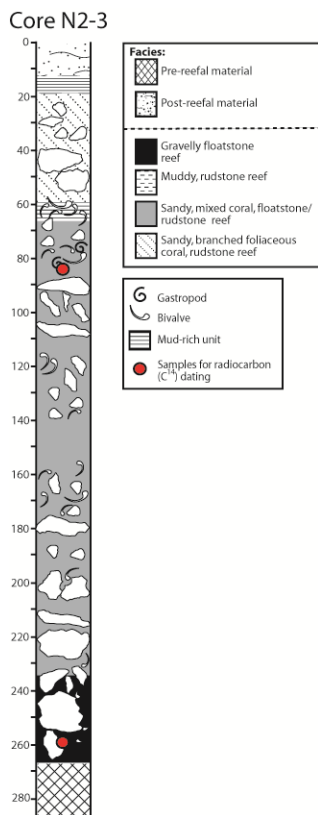


Figure 2 Core log for core N2-3



Figure 3 Core N2-3 (labeled below as PCMS1) sectioned and showing interval where clasts for N2-3 -85cm were selected

(‰ value) using an Optima Duel Inlet mass spectrometer. This value was used for isotopic correction in the calculation of the conventional ^{14}C age (yr BP) for each sample.

Quality Control

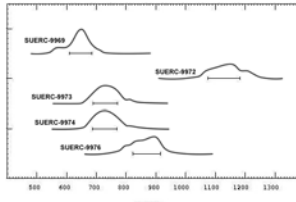
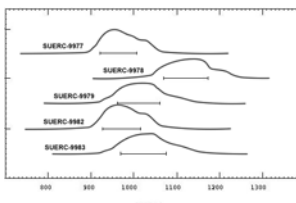
For purposes of quality control, an aliquot of IAEA-C2 of a similar size to the samples was used as a process standard and hydrolyzed to CO_2 , graphitized, and analyzed at the AMS at the same time as the samples. $\delta^{13}\text{C}_{\text{VPDB}}$ (‰) and ^{14}C (pMC) results for this standard are within 1σ confidence limits of the international consensus value at $8.56 \pm 0.1\text{‰}$ and 41.21 ± 0.18 pMC, respectively (Rozanski et al. 1992).

RESULTS AND DISCUSSION

Results are presented in Table 1 and a marine reservoir effect correction of $\Delta R = +12 \pm 10$ yr BP (Ulm 2006) was applied to the dates during calibration to calendar years using the calibration program CALIB 6.0 (<http://calib.qub.ac.uk/calib/calib.html>) and the Marine09 data set (Reimer et al. 2009).

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Table 1 Conventional ^{14}C ages (yr BP) and calibrated ages^a (cal BP) for samples from Core N2-3.

Lab code	Species	$\delta^{13}\text{C}_{\text{VPDB}}$ $\pm 0.1\text{‰}$	^{14}C age yr BP (1 σ)	Age cal BP (1 σ)	Age cal BP (2 σ)	Probability distributions* (2 σ)
N2-3 -85cm						
SUERC-9969	<i>Turbinaria</i>	-0.6	1092 \pm 41	610–684	552–715	
SUERC-9972	<i>Favia</i>	-5.3	1589 \pm 35	1075–1183	1043–1240	
SUERC-9973	<i>Turbinaria</i>	-1.6	1209 \pm 35	688–772	658–834	
SUERC-9974	<i>Turbinaria</i>	-0.4	1207 \pm 35	687–769	657–830	
SUERC-9976	<i>Acropora</i>	2.2	1338 \pm 35	823–916	772–943	
PSMC-1 -260cm						
SUERC-9977	<i>Turbinaria</i>	-1.7	1436 \pm 35	921–1007	896–1059	
SUERC-9978	<i>Turbinaria</i>	-0.2	1580 \pm 35	1068–1172	1031–1236	
SUERC-9979	<i>Turbinaria</i>	-0.5	1487 \pm 35	962–1060	928–1123	
SUERC-9982	<i>Turbinaria</i>	-0.5	1444 \pm 35	927–1015	900–1065	
SUERC-9983	<i>Turbinaria</i>	-1.4	1498 \pm 35	970–1075	938–1137	

^aCalibration was conducted using $\Delta R = +12 \pm 10$ yr, calibration program CALIB 6.0, and the Marine09 data set; * = 2 σ confidence level age ranges reported for relative area probabilities of 1.000 for all samples.

N2-3 -85cm

Turbinaria, *Acropora*, and *Favia* corals were dated in this facies. $\delta^{13}\text{C}_{\text{VPDB}}$ (‰) values for this group range between -5.3 and 2.2‰ . It is widely accepted that marine carbonate ^{13}C ‰ values fall within the range of $+2.0$ to -2.0‰ , and 2 samples, SUERC-9972 and SUERC-9976 have ^{13}C ‰ values that fall outside this range at -5.3‰ and 2.2‰ , respectively. It can be argued that SUERC-9976 overlaps at 2 σ confidence limits with the upper value of 2.0‰ for marine carbonates if the analysis error ($\pm 0.1\text{‰}$) is taken into consideration; however, SUERC-9972, a *Favia* species, does not overlap with the accepted range for marine carbonates when the analysis error was taken into account. It is difficult to explain the value for SUERC-9972 as published $\delta^{13}\text{C}_{\text{VPDB}}$ (‰) values for *Favia* species fall within the accepted range for marine carbonate (Wang and Huang 1989; Chakraborty and Ramesh 1998), the facies would generally be considered too young to have undergone significant diagenesis and $\delta^{13}\text{C}_{\text{VPDB}}$ (‰) and ^{14}C (pMC) values for the associated process standard are excellent.

Calibrated ^{14}C ages (cal BP) for this group range from 553–716 to 772–949 cal BP. SUERC-9972 is significantly older and does not overlap at 2 σ probability ranges with any of the other samples in this group. Examination of the sedimentary fabric of the core does not suggest that there has been extensive reworking of the sediment, but as this sample may suggest, localized and small-scale reordering of clasts may occur during depositional events.

Of the remaining samples 2 overlap at the 1 σ calibrated age range and both of these samples overlap at 2 σ calibrated age ranges with the other 2 samples (although all 4 samples do not overlap with each other at 2 σ).

N2-3 -260cm

Turbinaria samples were dated in this facies. $\delta^{13}\text{C}_{\text{VPDB}}$ (‰) values range from -1.7 to -0.2‰ , falling within the expected range for marine carbonates. ^{14}C (yr BP) data from the N2-3 -260cm horizon

range from 1444 ± 35 to 1580 ± 35 and are in excellent agreement with 4 of the 5 calibrated ages overlapping at 1σ confidence limits. All 5 calibrated ages overlap at 2σ confidence limits.

CONCLUSION

Our data suggest that coral clasts derived from branched and plate-like coral taxa can be used for ^{14}C dating to establish accurate chronologies if the samples are carefully chosen and pretreated to avoid coralline encrustations and skeletal alteration (Kennedy and Woodroffe 2004; Perry and Smithers 2006) and samples with $\delta^{13}\text{C}_{\text{VPDB}} (\text{‰})$ values that deviate from the expected marine carbonate value are rejected for use in chronology building.

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